

# WOMEN'S HIGH HEEL DISCOMFORT ANALYSIS AND PROTOTYPE SOLUTION

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**ABSTRACT**  
**WOMEN'S HIGH HEEL DISCOMFORT ANALYSIS AND SOLUTION**

Kevin Blakley and Annamarie Kepple

Women love high heeled shoes, but this love comes at the cost of comfort. Wearing high heels causes a lot of pain and, in the long term, health complications. This project tries to overcome the problem by ultimately making high heels more comfortable. In order to do this, one must first understand the reasons that high heels are uncomfortable, such as arch angle, heel height, and the changes in walking motion. Once there is a true understanding of the factors that contribute to high heel discomfort, the design stage can begin.

The design selected for this project was a wedge heel that contained compressive material. This design would improve user comfort in four different criteria. These criteria were arch angle, compression of the shoe, foot rotation, and ground contact surface area of the heel. After the working prototype was created, it was performance tested in these four criteria against a standard stiletto heel and a standard wedge. The results of the prototype showed a great improvement in all of these criteria, resulting in a more comfortable high heel. However, there were a few areas that this prototype and the production process could be improved upon in the future. First, the prototype weight was a critical design factor, which resulted in a heel that is noticeably heavier than a standard high heel. Next, the cost to produce the prototype is much higher than is economically preferable if the shoes were to be sold for profit. Finally, a more refined manufacturing process would be more beneficial in creating a more aesthetically pleasing product.

## **ACKNOWLEDGMENTS**

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## INTRODUCTION

This senior project report focuses on the various factors that contribute to high heel user discomfort and the prototype created to reduce this discomfort. The idea for this project originated from the observation of numerous women voicing extreme discomfort and pain when wearing high-heeled shoes. In some circumstances, it was observed that users would resort to removing their high heels due to extreme pain. Therefore, this project was focused on the discomfort that high heels cause their users, the small amount of wear time possible, and the probability that users remove their shoes due to this discomfort.

The purpose of this project was to provide women with a high heel shoe option that does not cause the user as much discomfort as traditional high heel shoes, if any discomfort at all. In addition, this project aimed to increase the amount of time a person could wear high heels without pain and reduce the possibility of the user removing their high heels. These project goals were met by achieving the following objectives:

- Survey of high heel users to assess discomfort factors and preferred features that users would prefer in a comfortable high heel
- Analyze results from initial user survey
- Determine different design alternatives for high heel prototype
- Select best prototype design based on decision matrix
- Create a working prototype of comfortable high heel solution
- Test prototype on a group of users for comfort and feasibility
- Test prototype performance of decision matrix criteria

- Create a plan for the mass production of the comfortable high heel solution
- Create an economic analysis of the production costs of the high heel solution

As outlined in the objectives above, this project focuses on the prototyping of a high heel solution. This project does not include work related to the creation of a shoe company, such as marketing or distribution. Any other deliverables not outlined above are out of the scope of this project.

This project's solution was reached by following 6 main steps:

1. User Research and creation of design specifications
2. Extensive design brainstorming
3. Creation of decision matrix to weigh design alternatives against important criteria
4. Selection of best prototype design by analyzing decision matrix
5. Design and material experimentation
6. Alteration of the design

The rest of this report is organized to provide background information related to high heels and their effect on the human body, as well as, review the 6-step solution approach that led to the creation of the working prototype. In addition, this report will include prototype test results, related conclusions, and overall solution feedback.

## BACKGROUND

The book Feet and Footwear: A Cultural Encyclopedia by Margo Demello is about the cultural impact of footwear. It focuses on the evolution of high heel design with a perspective on popular culture. It follows the history of high heels as a practical tool and their transformation into a fashion statement. In addition, the book discusses how social status is a factor for why heels became so popular. In the 1600s, European customs had traveled across the Atlantic to America where high heels were a symbol of wealth and were worn both by sexes (Demello 159). This unisex trend came to a crashing halt with the coming of the Revolutionary War. High heels were seen as a symbol of aristocracy, which Americans had come to mistrust (Demello 159). For this reason, high heels became increasingly unpopular in America and heels higher than 1 inch were very seldom worn by both sexes (Demello 160). High-heeled shoes became popular in American fashion by the end of the 19<sup>th</sup> century, but only with women (Demello 160). Men's heel height stayed at around 1 inch, while women's heels began exploring heights of 2 inches (Demello 160). This began the modern association of high heels and femininity that has lasted to this day (Demello 161). In more recent years, the concept of woman's health has been a hot topic, and the association with high heels and high fashion has become synonymous with foot discomfort (Seferin, and Linden 1). High heels are commonly blamed for health-related problems from joint problems to back alignment issues (Seferin, and Linden 1). "Protection or pleasure: female footwear" by Mariana Seferin and Julio van der Linden is a literature analysis of women's footwear and how it has evolved. Its main focus is to discuss women's fascination with shoes and why they go to such great lengths and put up with extreme discomfort in order to feel beautiful. It



would be very simple to design a comfortable shoe, but that does not necessarily mean women would wear it (Seferin, and Linden 2). In order to create a comfortable high heel, one must first understand why women love high heels and what makes them pick certain shoes over others. A critical factor is making a shoe that can be styled differently so it will be able to adapt to ever-changing fashion trends (Seferin, and Linden, 3).

High heel discomfort is a result of many different factors. The first contributing factor is the relationship between heel height and pressure distribution (Luximon, Luximon, Yu, and Zhang 2). The article “Biomechanical Evaluation of Heel Elevation on Load Transfer - Experimental Measurement and Finite Element Analysis” by Yan Luximon, Ameersing Luximon, Jia Yu, and Ming Zhang is the result of an experiment that studied how heel height alters the weight distribution on the foot. The study was performed by having participants stand on a pressure gauge that was angled to three different heel height levels: 0cm, 5.1cm, and 10.2cm. At each level, participants were asked to adjust their weight between each foot in order to fluctuate the weight distribution, similar to walking (Luximon, Luximon, Yu, and Zhang 2). The results showed as that as the heel height was increased, more weight was supported towards the ball of the foot. A 3D analysis of stress loads was performed on a digital model of the female foot for each heel height level. At the highest angle, a pressure of .20 megapascals was found near the ball of the foot (Luximon, Luximon, Yu, and Zhang 6). The study concluded that heel height plays a critical role in pressure distribution across the foot, and consistent wearing of high heels could greatly increase one’s chance of foot problems (Luximon, Luximon, Yu, and Zhang 7). This article demonstrates that heel height is a large factor that contributes to high heel discomfort. If high heels are to be made more

comfortable, the shoe design must distribute the high pressure to other parts of the foot or lower the foot angle (Luximon, Luximon, Yu, and Zhang 7).

Another factor is the surface area of the heel that is in contact with the ground. “Effect on Plantar Pressure Distribution With Wearing Different Base Size of High-Heel Shoes During Walking and Slow Running” by Lan-Yuen Guo, Chien-Fen Lin, Chich-Haung Yang, Yi-You Hou, Hung-Lin Liu, Wen-Lan Wu, and Hwai-Ting Lin is a report about an experiment that focused on movement in high-heeled shoes. The experiment was split into two sections. The first section focused on slow-paced walking in heels of different heights. The second section focused on having participants run at a faster pace. For both sections of the experiment, the pressure distributions were calculated throughout the foot. The base of the heel was a critical variable within the study, and the study found that a wider heel base reduces pressure on the front of the foot (Guo, Lin, Yang, Hou, Liu, Wu, and Lin 4). A sturdy heel base allows for the weight to be carried on the heels of the user, ultimately releasing pressure on the toes and ball of the foot (Guo, Lin, Yang, Hou, Liu, Wu, and Lin 4). Having a wider base makes walking easier and reduces the risk of sprained ankles and other related injuries (Guo, Lin, Yang, Hou, Liu, Wu, and Lin, 5).

Decreased torque received by the ankle is another complication of walking in elevated shoes, resulting in a less natural walking motion (Kerrigan, Todd, and O Riley 2). The article “Knee Osteoarthritis and High-Heeled Shoes” by D Casey Kerrigan, Mary K Todd, and Patrick O Riley focuses on how high heels alter the leg joint stresses of the user. In a high heel shoe, the ankle is locked in place and not allowed to rotate in a natural heel-to-toe motion (Kerrigan, Todd, and O Riley 2). The study determined that

there is a reduction of torque in the ankle while wearing high heels (Kerrigan, Todd, and O Riley 2). Because of this torque reduction in the ankle, the other leg joints have to compensate in order to balance out the forces that are applied to the body (Kerrigan, Todd, and O Riley 3). This has dramatic results on the rest of the body. Since the ankle does not absorb all of the torque, it is distributed to other joints in the body, which possibly causes knee, back, and hip problems (Kerrigan, Todd, and O Riley 2). All three of these factors must be addressed to create a comfortable high heel.

This website “Madehow.com” goes in depth about high heel construction and manufacturing process. It gives a background on high heels including a brief history, and then jumps into the material selection process. The most common materials used in a high heel are plastic, leather, wood, metal, and fabrics ([www.Madehow.com](http://www.Madehow.com)). Next, it discusses the design of heels, and how a heel can be broken down into different sections. Normally, shoes are made from combining three different parts: the heel, the sole, and the upper ([www.Madehow.com](http://www.Madehow.com)). After these three sections are made, they are normally glued together using strong cement. It is not uncommon to use tacks or screws to secure the heel in place as well ([www.Madehow.com](http://www.Madehow.com)). Since the deliverables of this project will greatly be affected by the design and manufacturing process, it is imperative to understand how high heels are traditionally manufactured to troubleshoot before problems even arise.

A product that has attempted to solve the problem of uncomfortable high heels is the Camileon High Heel. Their design features a stiletto heel that can convert from a high heel to a kitten heel. This conversion is done by pulling on a lever mechanism located

half way up the heel and folding the heel forward under the arch of the foot (www.camileonheels.com, Technology). Ultimately, the heel could lower from a height of 3.25 inches down to 1.5 inches (www.camileonheels.com, Technology). Lowering the heel height does a good job of overcoming the factors of high heel discomfort. It lowers the arch angle, thus decreasing the pressure on the balls of the feet and toes. The lower arch angle also allows for more torque to be absorbed by the ankle (Kerrigan, Todd, and O Riley 2). However, the Camileon high heel design does not factor in a wider ground contact surface area, which would provide increased heel stability (Guo, Lin, Yang, Hou, Liu, Wu, and Lin 4). While this design may be desirable at its lower heel height, this design does nothing to increase comfort when the shoe is at its full heel height of 3.25 inches. This company is currently selling these shoes online targeted for women in a business setting and has patents to protect their technology (www.camileonheels.com).



**Figure 1: Camileon High Heel Design**

(<http://www.camileonheels.com/technology.htm>)

Alfredo Louis Morales of MIT attempted to tackle the challenge of reducing high heel discomfort as well. His final design was very similar to the Camileon Heel. He took preexisting high heel shoes, dismantled them, and created a detachable heel system where the heel could be taken off, slid underneath the arch, and secured into a groove. This process has the same advantages and disadvantages as the Camileon Heel.

This project is necessary due to the fact that no one has found a permanent solution to high heel discomfort. While the Camileon Heel and Morales came close to finding an elegant solution, they still have problems. When the Camileon heel is folded underneath the arch of the foot, it is still visible and looks aesthetically unappealing. Morales's solution of removing the heel creates the problem of what to do with the heel after it has been removed, and how to replace the heel if it is lost. In addition, both of these designs did not address a way to reduce user discomfort at the high heel height setting. An elegant solution that reduces user discomfort at a high heel height is still needed.

## Heel Style Background

In order to assist with term comprehension later in this report, terminology related to different heel styles will be reviewed in this section. In total, 4 heel styles will be reviewed.

### 1. Pump

A pump is what most people are thinking of when they think of a classic professional shoe. They consist of a low cut front to expose the top of the foot and usually do not have any fastening or straps. Modernly, a pump is known for having a wider, non-stiletto heel and usually has a heel height of approximately 3 inches. However, a pump can technically have a stiletto heel. If this is the case, it is commonly referred to as a stiletto, not a pump.



**Figure 2: Pump High Heel**

([http://upload.wikimedia.org/wikipedia/commons/4/45/Red\\_High\\_Heel\\_Pump.jpg](http://upload.wikimedia.org/wikipedia/commons/4/45/Red_High_Heel_Pump.jpg))

## 2. Stiletto

A stiletto heel is commonly known for its long, thin tapered heel. A stiletto can be on a shoe like a pump or can be added onto a boot. A stiletto can vary in length from 1 inch to 8 or more inches, if a platform is used. However, a stiletto heel height below 2 inches is commonly referred to as a kitten heel. Modernly, most women would refer to a stiletto as having a heel height of 4 inches or taller. Most stiletto heels have a diameter of .5 inches at the bottom of the heel where it meets the ground, which adds to the reputation of a stiletto being very difficult to walk in.



**Figure 3: Stiletto High Heel**

(<http://www.duggal.com/connect/wp-content/uploads/2010/10/heel.jpg>)

## 3. Platform

A platform is a shoe, boot, sandal, or heel that has an extremely thick sole that provides additional height to the shoe. A platform heel commonly has additional sole thickness under the ball of the foot, and a tall heel height to

accommodate for the additional front sole height. This additional front sole thickness usually leads to a less steep arch angle of the shoe. Modernly, a platform's heel thickness is comparable to that of a pump, rather than a stiletto, in order to add stability to the foot at the raised height.



**Figure 4: Platform High Heel**

(<http://lubasfashions.com/wp-content/uploads/2012/04/platform-shoes1.jpg>)



**Figure 5: Kitten High Heel**

(<http://nerdatthecooltable.com/wp-content/uploads/2012/10/kittenheel.jpg>)



#### 4. Wedge

A wedge is known for having a sole that spans from the ball of the foot and to the heel so that there is no gap between the ball of the foot and the heel. A wedge can be on a shoe to create a wedge heel or a boot. This wedge sole allows for greater contact surface area with the ground, and therefore increase stability.



**Figure 6: Wedge High Heel**

(<http://ak1.ostkedn.com/images/products/L12015621.jpg>)

## DESIGN

As stated in the Introduction section, there were 6 specific steps that were executed in order to arrive at the final prototype design before production. To review, these steps were:

1. User Research and creation of design specifications
2. Extensive design brainstorming
3. Creation of decision matrix to weigh design alternatives against important criteria
4. Selection of best prototype design by analyzing decision matrix
5. Design and material experimentation
6. Alteration of the design

### **Step 1 - User Research and Design Specifications**

This project began with completing the first objective of creating an initial user survey. This survey was created in order to investigate into various user preferences and discomfort caused by wearing high heels. The survey, which can be found in the Appendix section, asked ten questions that investigated the following user factors:

- Preferred high heel styles
  - Options included: Wedge, Platform, Stilettos, Pump, and Other with a box for additional details.
- Preferred heel heights
  - There were five options in one-inch increments from 1 inch to 5+ inches. There was also an “Other” option that allowed for additional details.

- Frequency that the user wears high heels
  - Options included: Once a month, Once a week, Every couple days, Weekends only, Everyday, At work only, Never, and Other with a box for additional details.
- Description of qualities that contribute to the comfort of the user's favorite pair of high heels
- Duration of comfortable high heel wear when standing
  - There were 6 options in hour increments that from less than 1 hour to 5+ hours. There was also an "Other" option that allowed for additional details.
- Duration of comfortable high heel wear when walking or dancing
  - There were 6 options in hour increments that from less than 1 hour to 5+ hours. There was also an "Other" option that allowed for additional details.
- Considerations when purchasing a new high heel
  - This question asked users to rank the following 6 considerations in order of importance: Style, Color, Height of Heel, Comfort, Brand, and Cost.
- Foot areas that felt discomfort after wearing high heels
  - Options included: Back of heel, Arches, Toes, Side of Foot, Top of foot, and Other with a box for additional details.
- Body areas that felt discomfort after wearing high heels
  - Options included: Calves, Thighs, Knees, Back, Ankles, Hips, and

Other with a box for additional details.

- Possibility of removing high heels due to extreme discomfort
  - This was a Yes or No response question

The survey was completed by utilizing an online surveying site and distributed to 200+ females through Facebook. In total, the survey produced approximately 145 responses.

After reviewing the survey responses, it became clear to us that a couple areas of the survey could have been improved for clarity or inclusion of common responses. The areas of the survey that could have been improved were:

- Adding a “special occasions” option to frequency of high heel wear
- Adding of “a couple times a month” option to frequency of high heel wear
- Adding of “ball of foot” to the foot areas that felt discomfort
- Did not explicitly specify if 1 was the most important for the ranking of purchase considerations

Even though the addition of these options would have been beneficial, the survey was still able to catch these different preference responses since all questions provided an “other” response option.

All survey results were reviewed and the following user trends were noted:

- A pump design was the most preferred style of high heel, followed by the wedge heel design.
- Most women preferred a heel height between 3-4 inches
- Most women attributed the comfort of their favorite heels to either additional sole cushioning by means of an insert, or a larger heel width or wedge

- Comfort was the third purchase decision priority. Style was first, followed by cost
- The toes were the number one area of the foot that most women experienced discomfort in. Second was arches, followed by ball of foot
- The calves were the other bodily area that most women experience discomfort in
- Most women said that they could only last 1-2 hours both standing and walking in their heels
- 90% of women admitted to removing their heels due to pain

Given these user trends, the following design specifications were created for the prototype:

1. Heel height between 3 and 4 inches

This heel height was chosen since most women from user survey responded with a preferred heel height of either 3 or 4 inches tall. A bar graph depicting these results can be found in the Appendix.

2. Increased natural foot rotation when walking compared to a standard high heel
3. 25% increase in material compression compared to a standard high heel

This specification of increased material compression was added in order to help increase the natural foot rotation specification outlined above. The compression of the material would allow for the foot to begin a walking stride at a lower angle than a hard heel material. In addition, a compressive heel material would absorb some of the shock of a walking stride that normally transfers to ankle and knee. This specification was

also added to assist with user sole comfort since a majority of women surveyed mentioned that their most comfortable heel provided additional sole cushioning

#### 4. Decreased arch angle compared to standard heel

A decreased arch angle would benefit user comfort in three ways. The first would be that the heel would better support the arch of the foot since the heel would be able to be in contact with the arch of the foot at a decreased angle. The second would be that the decreased angle would prevent the toes of the user from sliding into the front of the heel, causing pain and possibility leading to the removal of a toenail. The final way is that a decreased arch angle would alter the pressure distribution of the foot to decrease the pressure on the ball of the foot. When barefoot, the pressure is equally distributed between the ball of the foot and the heel. This is beneficial since the heel of the foot is designed to be able to hold all of the pressure of a human's weight. However, when the arch is at a higher angle similar to wearing high heels, the pressure is only distributed to the ball of the foot. Creating a prototype with a lower arch angle would allow the pressure distribution to spread to include the heel. Though the pressure would still not be equally distributed between the heel and the ball of the foot at a lower arch angle, this would decrease the pain users normally feel in the ball of their foot. Overall, this lower angle would help decrease discomfort in the top 3 foot areas women reported they feel pain in the user survey – toes, arches, and ball of the foot.

## 5. A wedge design

The decision to create a prototype that followed a wedge design was made in order to increase the ground contact surface area of the heel. This increase ground contact surface area would improve the user's stability when both standing and walking. Many women mentioned in the user survey that their favorite pair of heels was a wedge since they were easier to walk in. Even though this decision goes against the preferred heel style result from the user survey, the pump design, the second most preferred heel style of a wedge was a better decision in order to increase the user's stability and comfort.

### **Step 2 – Design Brainstorming**

After the trends from the user survey analyzed, it was now time to move onto the first step of the solution approach: design brainstorming. During the brainstorming process, 5 main designs came forth:

#### 1. A Convertible High Heel

This design would allow for a transformation from a full 3.5-inch heel to a smaller kitten heel of approximately 1 inch in height. In order to reduce the length of the heel, the heel would be able to collapse in on itself similar to a radio antenna.



**Figure 7: Sketch of Convertible Design**

## 2. Spring Design

This design would include a spring in the upper part of the heel that would compress under the weight of the user causing the lower part of the heel to go in on itself, ultimately reducing the total height of the heel.





**Figure 8: Sketch of Spring Design**

### 3. Compressive Material Design

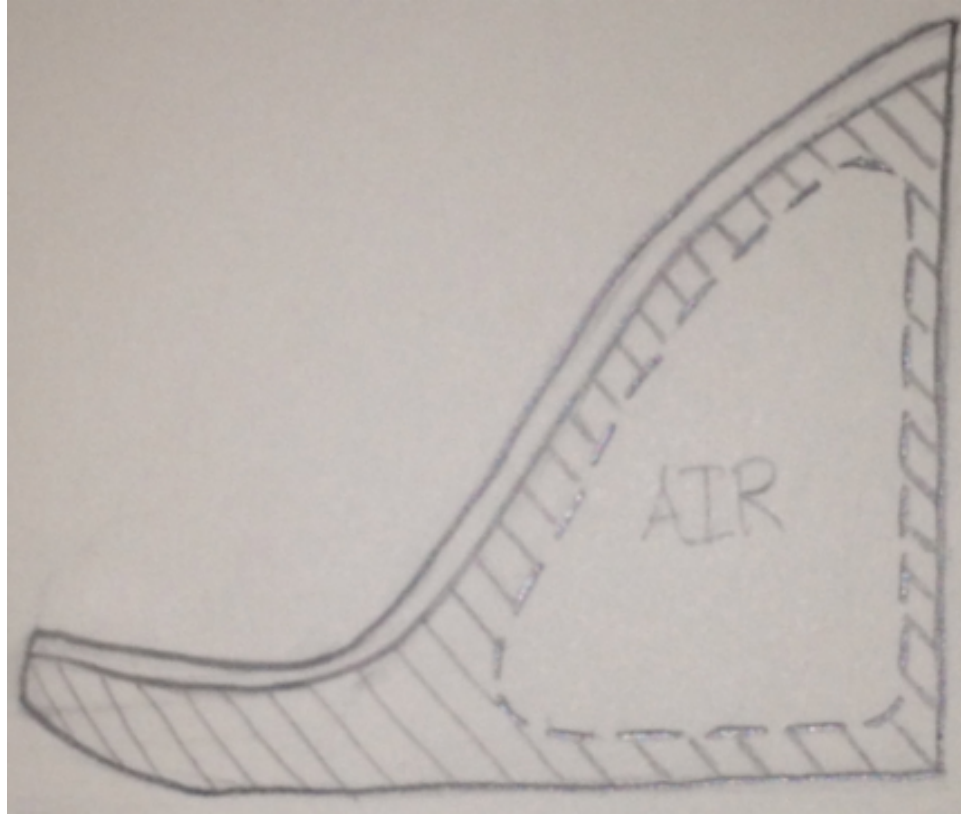
This design instead followed a wedge heel style that consisted of a material that could compress under the weight of the user. In addition, this design included a harder material layer along the bottom of the wedge to increase stability and prevent the heel from buckling under the weight of the user.



**Figure 9: Sketch of Compressive Material Design**

#### 4. Air Pocket Design

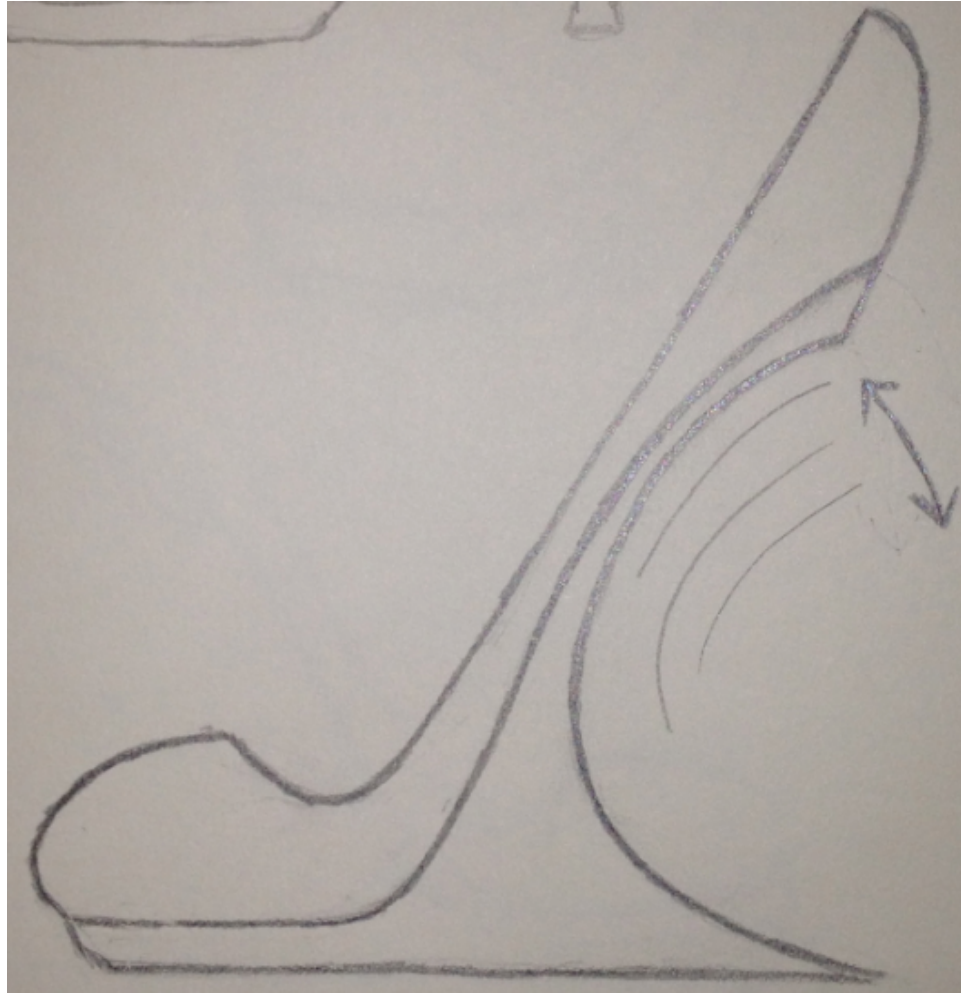
This design followed a wedge heel style as well. However, the wedge in this design would contain air pocket bladders that could be pressurized to allow for compression under the weight of the user. These pockets would have the ability to have customized pressure in order to have the precise and accurate compression for the user.



**Figure 10: Sketch of Air Pocket Design**

#### 5. U-Shape Arch Design

This design followed an altered wedge heel style that had material removed in a u-shape arch towards the heel of the wedge. This arch would act similarly to an archer's bow and would compress under the user's weight without fracture.



**Figure 11: Sketch of U-Shape Arch Design**

### **Step 3 and 4 – Decision Matrix and Design Selection**

In order to determine which prototype design would be the best solution, a decision matrix was created in order to weigh the solutions against important solution criteria. In declining importance, these criteria included:

- Allowance for natural foot rotation
- Material compressive ability – ball of foot and heel cushioning
- Arch Angle
- Ground Contact Surface Area
- Material Durability

- Style Flexibility
- Ability to convert from high heel to lower heel or flat
- Cost of Materials
- Ease of Implementation
- No Patents Exist

As seen in the decision matrix below in Table 1, each of these criteria were rated by importance and given a percentage out of 100 to help weigh the scores given to each of the design alternatives. All 5 design alternatives were rated in each of the 10 criteria on a scale from 1 to 10, where 10 was the preferred outcome for the prototype. After each alternative was rated in all ten criteria, an overall total score was calculated taking the weight percentage into account. This equation and a calculation example can be seen below in Equation 1 and 2. This equation and calculation example shows how each criterion's absolute weight is multiplied by the design's score in that criteria, added all together, and then multiplied by 10. This multiplication of ten is necessary since the initial summation of the products result in a score out of ten and a percentage score out of 100 was desired. The highest scoring alternative was the compressive heel material with a score of 67.1%. Therefore, this was decided to be the prototype design.

Criteria	Allows for Natural Foot Rotation	Material Compressive Ability - Ball of Foot and Heel Cushioning	Arch Angle	Ground Contact Surface Area	Material Durability	Style Flexibility	Ability to Convert from High Heel to Lower Heel or Flat	Cost of Materials	Ease of Implementation	No Patent Exists	Total	Out of Perfect Score
Importance (10 = highest, 1 = lowest)	10	9	8		7	6	5	4	3	2	1	55
Absolute Weight	18%	16%	15%		13%	11%	9%	7%	5%	4%	2%	100%
<b>Design Options and Rates for Criteria</b>	10 = High, 1 = Low	10 = High, 1 = Low	10 = Low, 1 = High	10 = High Surface Area, 1 = Low Surface Area	10 = High, 1 = Low	10 = High, 1 = Low	10 = Able 1 = Not Able	10 = Affordable, 1 = Expensive	10 = Easy, 1 = Hard	10 = No Patents, 1 = Patent		
1. Convertible Heel	5	2	5		1	10	7	10	7	4	1	5.09
2. Spring Heel	9	6	3		10	7	7	1	7	5	10	6.55
3. Compressive Heel Material	9	10	3		10	7	3	1	4	6	10	6.71
4. Air Pockets	7	7	1		10	5	1	1	4	5	10	5.13
5. U-Shape Arch	9	6	3		5	6	1	1	5	6	10	5.18

**Table 1: Design Decision Matrix**

Design Alternative Total Score =  $[\sum_{i=1}^{10}(w_i * s_i)] * 10$  where i = Design Criteria

**Equation 1: Design Alternative Total Score**

Weighted Design Alternative Total Score (Convertible Heel Design)

$$\begin{aligned} &= \left[ \sum_{i=1}^{10} (w_i * s_i) \right] * 10 \\ &= [(18\% * 5) + (16\% * 2) + (15\% * 5) + (13\% * 1) + (11\% * 10) \\ &\quad + (9\% * 7) + (7\% * 10) + (5\% * 7) + (4\% * 4) + (2\% * 1)] * 10 \\ &= 50.9\% \end{aligned}$$

**Equation 2: Convertible Heel Design Total Score**

**Step 5 – Design and Material Experimentation**

Now that a design had been selected, the next step in the solution approach was to experiment with how the prototype would be produced.

Initially, the plan to produce the prototype was to deconstruct a heel in order to have a standard upper and insole for the creation of the prototype. According to the “Shoe Dictionary” at Shoedigest.com, “the upper part of the shoe [is] made from a piece of leather to form the part that encases the foot, but does not include the sole. Uppers come in a variety of styles, some made from leather, fabric or synthetics” (“Shoe Dictionary” 6). Since the project’s goal was to focus on altering the heel portion of the shoe, not the upper, this approach would reduce production time. In addition, by having an upper and insole from a former heel, the sole would be able to hold the arch angle shape required for the prototype. Therefore, heels and wedges were purchased from Goodwill in order to remove the heel from the upper and sole. It was during this experimentation that it was discovered that most modern heels were connected to a rigid metal heel seat that made it impossible to detach the heel from the sole without destroying the rest of the sole. The heel seat is “...where the sole and the heel of the shoe are joined together...”

("Shoe Dictionary" 3). Therefore, a different approach of using a flat shoe for the upper and insole of the prototype was selected for prototype production.

Next, material analysis was performed in order to determine what type of material would be best to use for the compressive wedge prototype. At the recommendation of Cal Poly faculty member Martin Koch, an expert and lecturer in casting and molding, a consultation was scheduled with Mr. Brooke Wheeler of Smooth-On Materials. Smooth-On Materials specializes in "...rubbers, plastics, foams and other products to turn their ideas into 3-dimensional reality" ("About Smooth-On, Inc." 1). During this consultation, Brooke reviewed the different types of Smooth-On materials, provided a molding and casting demo, and provided one-on-one advising that took the prototype design and specifications into account. Brooke ended up recommending a two material approach to the compressive wedge design that would add a second, harder, thinner layer to the bottom of the compressive wedge in order to increase the wedge's stability. Given the desired amount of compression and other specifications, Brooke recommended that two different urethane rubbers be used in the wedge of the shoe. The first was a urethane rubber from their VytaFlex line with a Shore A hardness of 20 shores ("VytaFlex® Series Urethane Rubber Product Information" 1) that Brooke believed would be able to achieve the desired compression while still providing enough stability to support the user without the possibility of twisting an ankle. The second was a hard urethane rubber from their PMC line that was specifically known its rigidity, tear strength, and tensile strength and contained a Shore A hardness of 90 shores. Brooke recommended this rubber for the bottom harder layer in order to provide the shoe with some additional structure stability.

**Step 6 –Alteration of Design**

After the design and material experimentation, the design was altered to include an upper and sole from a flat instead of a heel. In addition, the design was altered to include two materials in the wedge in order to increase the stability of the heel. It was also determined what material types would be used in the wedge in order to meet the design specifications

The next section, Methods, goes into the details of how the prototype was produced as well as how the prototype was tested.



## **METHODS**

This section will review how the prototype was produced and what testing was performed to measure its success.

### **Prototype Production**

The production of this prototype was broken up into the following 6 steps:

1. Flat Sole Preparation
2. Mold Creation
3. Harder, Base Layer Pour
4. Alteration of Mold
5. Second Layer Pour
6. Finishing

This Prototype Production subsection will be split down further into 6 subsections that contain the details of these steps.

#### **Step 1 - Flat Sole Preparation**

This prototype process began by prepping the flats that would be used for the upper and insole of the prototype. Two sets of flats were purchased from Ross, one for the upper and insole, and the other for the outer sole. The first set of flats was prepared by removing the middle arch area of the outer sole of the flat. This allowed for the flat to be flexible to create a higher arch angle later in the prototype process. Figure 11 below shows the flat before the arch outer sole material between the two chalk lines was removed. The outer sole material was removed to the mid sole with a Dremel rotary tool while the flat was clamped down.



**Figure 12: First Flat Before Preparation**

The second set of flats was prepared by removing the entire outer sole from the upper and insole of the shoe. This would provide us with an outer sole for the prototype for traction and stability. First the upper material was cut down close to the outer sole with an x-acto knife and the additional material was removed with the Dremel tool. The final bottom sole can be seen below in Figure 12.



**Figure 13: Second Flat Outer Sole Preparation Result**

### **Step 2 - Mold Creation**

Next, the mold for the first pour of the harder, base layer was created. For the walls of this mold, it was required that the material was smooth, flexible to bend into the shape of sole, and would still be strong enough to hold its shape under the weight of the pour materials. Two rubber totes from Michael's were purchased to create the walls of the mold. This material could be cut with an x-acto knife into the length and shape that could encompass the outer sole. In order to increase mold stability, the outer sole was hot glued to a piece of cardboard. Then, the rubber material was cut to a long length and hot glued so that it was encompassing the entire outer sole. Lastly, the rubber walls were lined with turtle

wax in order to prevent the urethane rubber from sticking to the rubber walls and make the demold process easier. The finalized first mold can be seen below in Figure 13.



**Figure 14: Mold for First Pour**

### **Step 3 – Harder, Base Layer Pour**

For the next step of pouring the base layer, it was necessary to calculate how many cubic inches of urethane rubber material would be needed. This requirement was determined by multiplying the surface area of the outer sole by the desired thickness to get cubic inches, and then converting that to milliliters. The equation and calculation are seen below. According to the calculation, the first pour required 156.7 milliliters of urethane rubber material. The desired

thickness was determined by the urethane rubber's specifications of needing to be a minimum thickness of 0.5" in order to still meet the promised tear and tensile strength.

$$\begin{aligned} & \text{Amount of Urethane Rubber Needed (milliliters)} \\ &= \text{Surface area} * \text{desired thickness} * \text{conversion rate} \\ &= [8.5" * ((3" * 1.5")/2)] * 0.5" * (1 \text{ milliliter} / 0.061024") \\ &= 156.70 \text{ milliliters} \end{aligned}$$

**Equation 3: First Pour Required Volume Amount**

This requirement was rounded up to 180 milliliters in order to accommodate for additional material being left behind in the mixing container, calculation allowances, and make the total required volume divisible by three. This requirement of the volume being divisible by three was because the 790 urethane rubber required a two-to-one mixing ratio for the two components, Parts A and B. Therefore, in order to achieve the desired 180 milliliters, 120 milliliters of Part A



would need to be mixed with 60 milliliters of Part B.

Next, the two parts were mixed together in a plastic mixing bowl with a rubber spatula. The harder 790 urethane rubber required constant stirring for 3 minutes before being poured, as seen in Figure 14.

**Figure 15: Mixing of Base Layer Materials**



After mixing, the rubber had a pot life of 20 minutes. A pot life is the amount of time after mixing is complete until the rubber begins to cure or harden. After pouring the material into the mold, which had to be poured in a constant stream into the lowest point of the mold in order to prevent bubbles, the mold had to sit for 48 hours to cure.

**Figure 16: Finalized Base Layer Pour**

#### **Step 4 – Alteration of Mold**

After the bottom layer of 790-shore urethane rubber had cured, it was now time to prep the mold for the second pour of the compressible 20-shore urethane rubber. In order to pour the second layer in the shape of a wedge with the upper sole on top, the back wall of the already existing mold was removed. Next, the first pair of flats that contained the upper part of the shoe was hot glued to the mold at an inclined angle with room below it to allow for space for the second pour. It was necessary to leave a space below the ball of the foot of at least 0.5” since the urethane rubber’s specifications of required a minimum thickness of 0.5” in order to still meet the promised tear and tensile strength. Then, the mold was altered to sit upright with the toe pointing towards the ground and the back of the heel upwards to allow for an opening for the material to poured through.



Additional rubber walls were added to the side walls of the mold towards the heel of the upper to prevent the second pour from overflowing. This new mold can be seen in Figure 16. As like with the first mold, the walls of the mold were layered with turtle wax in order to prevent from the urethane rubber sticking to the walls of the mold and to increase the ease of demolding.



**Figure 17: Bird's Eye View of Modified Mold Before Second Pour**

### **Step 5 – Second Layer Pour**

For the next step of pouring the second layer, it was necessary to calculate how many cubic inches of urethane rubber material would be needed. This was determined by using the same equation as the first pour. The equation can be seen above in Step 3. According to this calculation, the second pour required 238.64 milliliters of urethane rubber material.

$$\begin{aligned}
& \text{Amount of Urethane Rubber Needed (milliliters)} \\
& = [( \text{Surface area of rectangle} * \text{desired thickness} ) \\
& \quad + ( \text{Surface area of wedge triangle} * \text{thickness} )] * \\
& \quad * \text{conversion rate} \\
& = ([8.5" * ((3" * 1.5")/2)] * 0.5") + (0.5 * 5" * 2") * (1 \text{ milliliter} / 0.061024") \\
& = 238.64 \text{ milliliters}
\end{aligned}$$

**Equation 4: First Pour Required Volume Amount**

This requirement was rounded to 250 milliliters in order to accommodate for additional material being left behind in the mixing container, calculation allowances, and make the total required volume divisible by two. The 20 urethane rubber required a one-to-one mixing ratio for the two components, Parts A and B. Therefore, in order to achieve the desired 250 milliliters, 125 milliliters of Part A would need to be mixed with 125 milliliters of Part B.

Next, the two parts were mixed together in a plastic mixing bowl with a rubber spatula. The harder 20 urethane rubber also required constant stirring for 3 minutes before being poured. After mixing, the rubber had a pot life of 30 minutes. After pouring the material into the mold, the mold had to sit for 24 hours to cure.

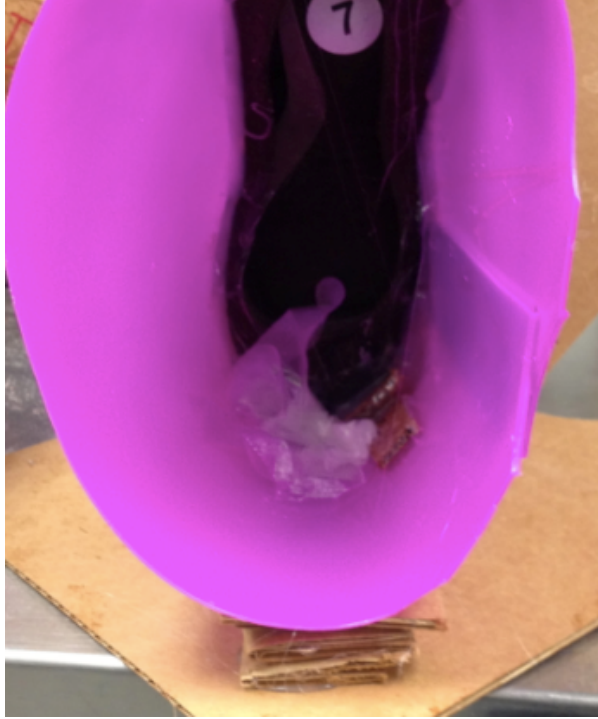
There were some complications with the second pour. The first complication was preventing the urethane rubber from overflowing onto the upper of the shoe at the top of the mold opening. Therefore, waxed cardboard was hot glued onto the heel of the upper as a wall to prevent this overflow, as seen in



Figure 17. After the wall was secure, the remainder of the mixture was poured up to the top of the heel. The second complication that occurred was that there was some leakage at the toe of the left shoe after doing the second pour. Luckily, the leak was spotted soon after the pour was completed and was able to be fixed before the pot life expired. In order to fix the leak, the urethane rubber was poured back into the mixing bowl, cardboard and plastic were added to fill the hole, and the hole was sealed with more hot glue. The ultimately sealed the hole, as seen in Figure 18.



**Figure 18: Finalized Second Pour**



**Figure 19: Complications with Second Pour**

### **Step 6 - Finishing**

After the 24 hour curing time was up, it was time to demold the shoe by removing the plastic, cardboard, and rubber walls. This was easily accomplished with some brute force. However, there was a lot of hot glue left behind. It was very difficult to remove the hot glue from the shoe with any power tools, like a Dremel, because it would melt the glue instead of removing it. Therefore, a more manual process of removing the hot glue with a knife was selected. This knife was also used to shape the back of the heel into a half circle shape since the mold gave the back of the heel a square-like shape. The finalized prototype can be seen in Figure 19 below.



**Figure 20: Finished Prototype**

### **Testing**

In total, the prototype was tested for four main criteria:

1. Material Compression
2. Arch Angle
3. Ground Contact Surface Area
4. Foot Rotation

This Methods subsection will outline how each of these prototype tests were performed.

### **Material Compression**

The first test performed was the high heel material compression test. The purpose of this experiment was to determine how much the heel compresses when it is under different loads. Heel compression will improve many high heel discomfort factors such as walking motion, pressure distribution, and ankle torque. The materials needed to conduct this experiment were 1 tape measure, the 3 different shoe models to be tested, and a woman to add a load to the shoes that would come in the form of a specified body weight. The experiment began by

placing the shoes with the toes facing away from the observer. A heel height base measurement for all three styles of shoes was taken with no load being applied to the shoe. Next, each shoe was loaded with 50% body weight in order to simulate an even weight distribution on both the right and left foot. These heel heights were recorded. Then, the full body weight was applied to the right shoe and then the left shoe by having the woman stand on one foot at a time. These heel heights were recorded.

### **Arch Angle**

The next factor that was measured was the arch angle. The arch angle determines where the center of pressure is located on the foot. As the arch angle increases, the pressure becomes more centered towards the front of the foot, thus becoming increasingly uncomfortable for the user. A low arch angle is desirable to increase high heel comfort. In order to determine the arch angle for testing, a tape measure and the three shoe models to be tested were needed. First, the shoes were placed at rest with no load and the following two components were measured:

1. The heights of the heels relative to the ball of the foot
2. The distance between ball of the foot and the heel

After these measurements were completed, a simple trigonometric calculation yielded the angle of the arch for each shoe. This equation can be seen below.

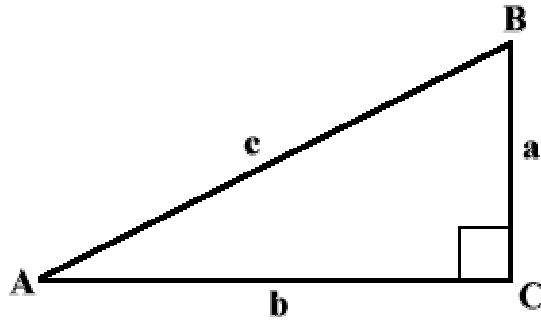


Figure 21: Sample Trigonometric Triangle

Equation 5: Arch Angle

**Ground Contact Surface Area**

The ground contact surface area was another criterion identified as a contributor to high heel discomfort. As ground contact surface area increases, the foot pressure is distributed over a greater area. This allows for more support while walking, which reduces the chance of a sprained ankle or other similar injuries. In order to measure the ground contact surface area, a ruler and the three different high heels were needed. Three different areas were measured for each shoe:

1. Heel
2. Toe
3. Under the arch, if it made contact with the ground

These three areas were added together to get an estimate of the shoes total surface area.

Equation 6: Ground Contact Surface Area

### **Foot Rotation**

The next test criterion was foot rotation. The objective of this test was to see if the prototype would increase the foot rotation while walking as compared to a standard stiletto heel. Need materials for this test was a camera, a stiletto heel, and the prototype, and a computer. The experiment began with a woman walking barefoot to determine her foot rotation under natural walking conditions. Photographs were taken from the side when her foot first came into contact with the ground, and when the foot had fully finished rotating at the end of her stride. These photos were then put on a computer and the angles were measured by sizing triangles with one end parallel to the ground and the hypotenuse parallel to the foot. Then, Equation 5, arch angle equation, was used to determine the foot angles at the beginning and end of the stride. The final foot rotation angle was calculated by taking the initial angle (A1) and subtracting the final angle (A2), as seen in the equation below.

$$\begin{aligned} \text{Angle Rotation} &= A1 - A2 \text{ where } A1 = \text{initial foot angle and } A2 \\ &= \text{final foot angle} \end{aligned}$$

Now that the prototype production and testing methods were discussed, next the report will address and discuss the results from these tests.

## RESULTS AND DISCUSSION

This results and discussion section will reveal the results from the tests described in the previous section. These test results will follow the same order as the Methods section:

1. Material Compression
2. Arch Angle
3. Ground Contact Surface Area
4. Foot Rotation

Then, this section will wrap up with a discussion of the economical analysis results.

### **Material Compression**

There was no observable compressive ability of the wedge high heel or the stiletto heel. The results of prototype compression test and related equations are in the Appendix. It was found that under weight evenly distributed between left and right foot, there was compression down to a height of 3.43 inches on the left foot and 3.56 inches on the right foot. This meant that both shoes compressed a total of .25 inches under evenly distributed weight, which was approximately 6.5% compression. This is 6.5% more compression compared to the stiletto and wedge heel that had 0% compression. When the entire weight of the user was applied to one shoe, the left foot compressed down a height of 3.43 inches and the right compressed to a height of 3.375 inches. This meant that each shoe compressed a total of .4375 inches under the entire weight. This compression for each shoe under the entire weight rounded to 11%. This was a great improvement from the stiletto and wedge heel, which had 0% compression. Even though the goal of 25%

compression was not reached, the prototype shows great gains over that of the stiletto and wedge. The material compression in the prototype results in increased foot rotation, increased ankle torque, and a pressure that is distributed away from the balls of the feet.

### **Arch Angle**

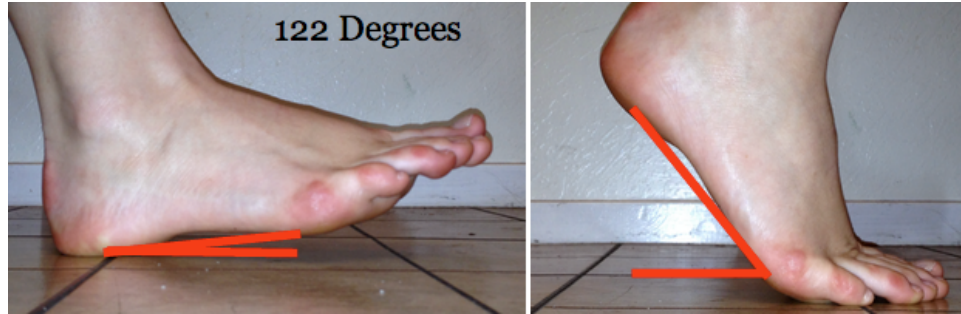
It was found that the stiletto heel had the largest angle of 48.81 degrees, followed by the wedge of 31.4 degrees, and the prototype with the smallest angle of 23.19 degrees. The results of prototype compression test are in the Appendix. This analysis shows that the prototype was successful in lowering the arch angle, thus moving the pressure distribution towards the heel, and increasing the ankle torque. These improvements assist in increasing the user's comfort.

### **Ground Contact Surface Area**

The final estimates of ground contact surface area were calculated using Equation 6. The wedge resulted in 13.45 square inches, the stiletto had 5.84 square inches, and the prototype had 19.71 square inches. This result shows a great improvement in ground contact surface area in the prototype from the stiletto and wedge. This added ground contact surface area would allow for the pressure to be distributed across the entire foot, thus lowering pressure point spikes that cause user discomfort. The increased ground contact surface area also has the added advantages of increasing user stability while walking, and decreasing the probability of spraining an ankle or any other related injuries.

### **Foot Rotation**

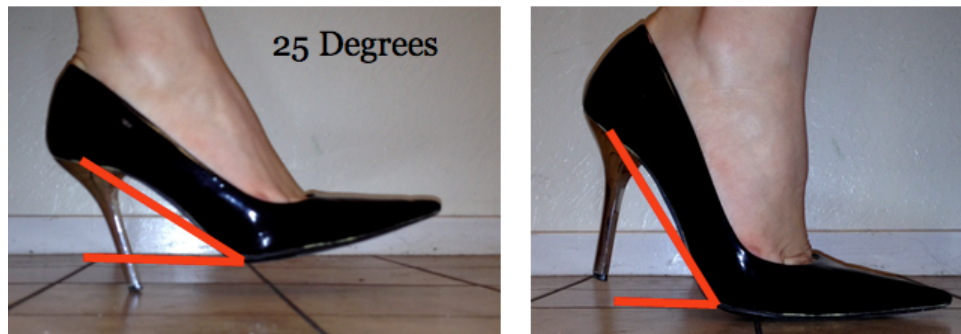




**Figure 22: Barefoot Foot Rotation**

$$\begin{aligned}
 \text{Foot Rotation (Barefoot)} &= \text{Initial Angle} - \text{Final Angle} \\
 &= (180 \text{ degrees} - 6.7 \text{ degrees}) - 51.3 \text{ degrees} \\
 &= 122 \text{ degrees}
 \end{aligned}$$

**Equation 7: Barefoot Foot Rotation Calculation**



**Figure 23: Stiletto Foot Rotation**

$$\text{Foot Rotation (Stiletto)} = 58 \text{ degrees} - 33 \text{ degrees} = 25 \text{ degrees}$$

**Equation 8: Stiletto Foot Rotation Calculation**



**Figure 24: Prototype Foot Rotation**

$$\text{Foot Rotation (Prototype)} = 53 \text{ degrees} - 6 \text{ degrees} = 47 \text{ degrees}$$

**Equation 9: Prototype Foot Rotation Calculation**

As seen above, the barefoot foot rotation was calculated to have a rotation of 122 degrees and the stiletto foot rotation was calculated to have a rotation of 25 degrees. The prototype nearly doubled the foot rotation of the stiletto heel with a foot rotation of 47 degrees. Although the prototype is still far from a natural foot rotation of 122 degrees, it showed great improvements over the stiletto high heel. Foot rotation is important for many reasons. It allows for the pressure to be distributed more towards the back of the foot by decreasing the initial foot angle. Also, increased foot rotation creates a longer lever arm that increases the ankle torque. Finally, it imitates a more natural walking motion by stretching the calf muscles and reducing the pressure on the ball of the foot.

**Final Design Review**

Even though the prototype was successful in improving the factors that were identified as uncomfortable, there is room for improvement. The first prototype issue is that the prototype is noticeably heavier than a standard high heel. This is a result of the wedge material that the prototype was made out of. If this project were to be continued, further material analysis should be completed in the attempt to lighten the shoe without sacrificing the quality of compression or structural stability. It is recommended to research into having lighter plastic balls within the wedge material to reduce the weight but still provide structural integrity. Another research recommendation would be to hollow out part of the wedge in a triangle shape in a fashion that would prevent the heel from buckling under a user's weight. Another factor that could be improved in the

material cost. The materials that went into making the prototype were very expensive and the cost should be a top priority for future endeavors.

### **Economical Analysis**

Next, an economical analysis was performed to look at the production of these shoes in a mass production setting. First, the production costs were calculated by taking the labor, material, and overhead costs into account. The labor costs were determined by estimating production time for one pair of shoes, calculating the cost per worker in a year, and determining how many units could be produced in one year to get the labor cost per unit. This labor cost was calculated with the assumptions that one unit is one pair of heels and the worker is working in California with a wage of \$12/hour. The individual material cost per unit was determined by multiplying the total cost for that material by the ratio of quantity used for the production of one unit. Then, these individual material costs were summed together to provide the total material cost for a production of one unit. The overhead calculations were split into two categories: initial startup cost and ongoing cost. The labor and material costs were added together give a unit variable cost of \$158.45. There was a calculated overhead of \$9420.00 and a total fixed cost of \$9556.13. Given that one unit took approximately 3.78 hours to produce, 550 units would be produced under one worker. Given this volume projection, there would be a total yearly cost of \$96701.35. All of these cost and volume calculations and relevant equations can be found in the Appendix.

Next, the sales price was calculated. A price margin of 20% was selected as an assumption, which resulted in a sales price per unit of \$190.14. Given this sales price and the assumption that all of the 550 units produced would be sold, there would be a

yearly revenue of \$104,574.27. This resulted in a profit of \$7,872.91 and provided a contribution margin of 17%. All of these calculations and relevant equations can be found in the Appendix.

Next, a breakeven analysis was performed under the assumption that the sales price per unit would stay constant at \$190.14. Under this assumption, it was found that the revenue required to breakeven would be \$57,336.78, which resulted in a breakeven volume of 301 units. This breakeven point could graphically be seen in Figure 20 below. All of these breakeven calculations and relevant equations can be found in the Appendix.

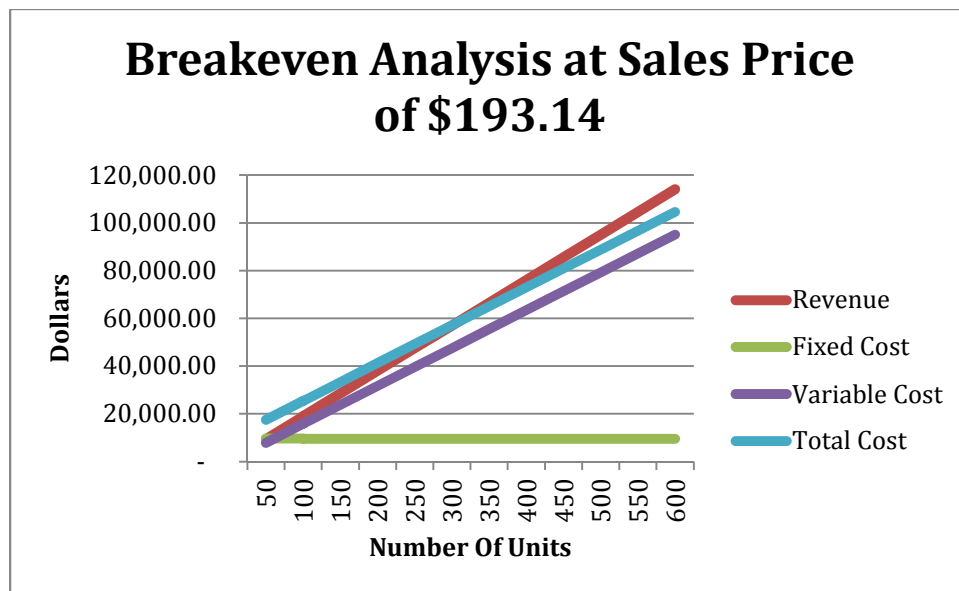
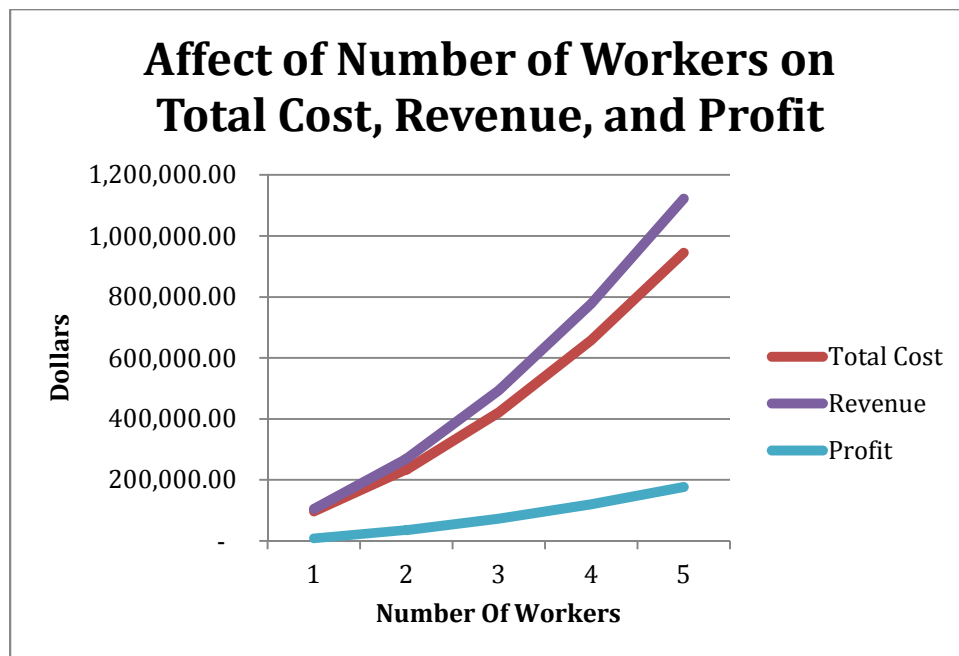


Figure 25: Breakeven Analysis Graph

After the breakeven point was determined, sensitivity analysis was performed to determine how the number of operators would affect cost, revenue, and the breakeven point. In order to do this, the labor cost was recalculated taking into account that 2, 3, 4 and 5 workers were producing units. The new labor costs for additional workers were determined by recalculating the wage cost per year and the working hours in a month to accurately represent the

number of workers. Then, the costs, volume, revenue, profit, sales price, and breakeven point were recalculated given the new number of workers and the related new labor costs. As seen in the figure below, as number of workers increased, revenue, total cost, and profit all increased. In addition, sales price increased as the number of workers increased due to higher unit variable costs. This increased sales price led to increased revenue. Increased revenue in combination with increased start up cost due to additional workers led to an increased breakeven revenue. Since sales price increased at a slower rate than breakeven revenue with each additional worker, the breakeven volume decreased as number of workers increased. All of this number of worker analysis calculations and relevant equations can be found in the Appendix.



**Figure 26: Graph of Number of Workers Effect on Total Cost, Revenue, and Profit**

The concept of how much sales price affects breakeven revenue was investigated further by calculating revenue for different sales price margins. The sales price per unit was determined by multiplying the variable unit cost by the sales price margin, as seen in the Appendix. Revenue was calculated assuming one worker was producing 550 units a year for increasing sales price

margins. As sales price margin increased, which caused the sales price to increase, the revenue increased. This increase in revenue resulted in breakeven sales price margin of approximately 11%. These results can be seen graphically below. In addition, it was found that as sales price margin increases, breakeven revenue and breakeven volume decreases. This decrease in breakeven revenue is due to a steep increase in the contribution margin. The decrease breakeven volume was due to the decrease in breakeven revenue and the increase in sales price. Theses decreases in breakeven revenue and breakeven volume can be seen graphically in the Appendix.

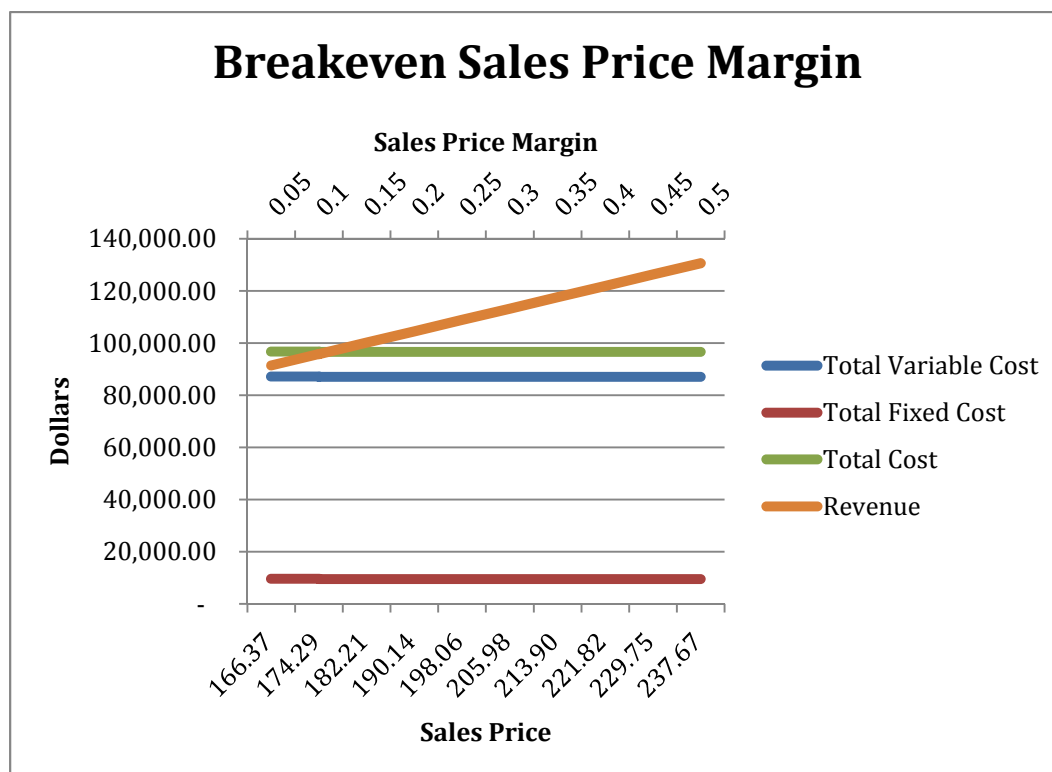


Figure 27: Graph of Breakeven Sales Point Margin

## **SUMMARY AND CONCLUSIONS**

Women love to wear high-heeled shoes for a magnitude of reasons ranging from increased height to feeling pretty. Unfortunately, there is a large amount of discomfort and negative health side effects associated with high heels. This discomfort frequently becomes too great and women resort to removing their heels to walk barefoot. This leaves their feet unprotected and vulnerable to other hazards. The main objective of this project was to solve problem of high heel discomfort. This was accomplished by first determining what factors contribute to discomfort, surveying women to determine their heel preferences, brainstorming potential solutions, building a working prototype, and testing it against performance criteria. To help narrow down the design options, a decision matrix was created to weigh each option against decided upon criteria. Ultimately, this led to the design that was selected.

The most impactful result from the prototype testing was the foot rotation. The prototype nearly doubled the foot rotation of a stiletto heel. This increase foot rotation also had a large effect on the overall comfort of the shoe. This project shows that high heel shoes can be made more comfortable by mimicking a more natural walking motion. Compression of the heel, lowered arch angle, and increased ground contact surface area greatly improves the walking motion of the user. All these factors together accomplish the project's goal of creating a comfortable high heel shoe. If this project were continued further, there are a few things that could be improved upon. First, the weight of the material should be a greater factor to consider. Second, exploration of more cost effective materials should be performed. Third, a more standardized and reusable molding and demolding process should be addressed since it would increase efficiency. The

prototyping method outlined in this report resulted in a prototype with a lot of glue still attached to it. Finally, the marketability of the product should be considered further. A fashion designer would have to be consulted to make the shoe esthetically pleasing so that it could be sold in retail stores.



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## APPENDICES

www.surveymonkey.com/s.aspx?PREVIEW\_MODE=DO\_NOT\_USE\_THIS\_LINK\_FOR\_COLLECTION&m=c92b8albSLwBeyer7K2bOSKCb8a5efEE4oCctC193szEPuK3d -- [SURVEY PREVIEW MODE] High Heel Conf... Reader

SurveyMonkey - Question Builder [SURVEY PREVIEW MODE] High Heel Comfort and Style Survey

### High Heel Comfort and Style

**1. How often do you wear high heels?**

☐ Once a month

☐ Once a week

☐ Every couple days

☐ Weekends only

☐ Everyday

☐ At work only

☐ NEVER

Other (please specify)

**2. What type of heels do you wear?**

☐ Wedge

☐ Platform

☐ Stilletos

☐ Pump

Other (please specify)

**3. What is the heel height that you prefer?**

☐ 1 inch

☐ 2 inch

☐ 3 inch

☐ 4 inch

☐ 5+ inches

Other (please specify)

Figure 28: Initial User Survey - Picture 1 out of 4

www.surveymonkey.com/s.aspx?PREVIEW\_MODE=DO\_NOT\_USE\_THIS\_LINK\_FOR\_COLLECTION&m=c92b8albSLwBeyer7K2bOSKCb8a5efEE4oCctC193szEPuK3d -- [SURVEY PREVIEW MODE] High Heel Conf... Reader

Facebook SurveyMonkey - Question Builder [SURVEY PREVIEW MODE] High Heel Comfort and Style Survey

**\*4. Please describe what about your favorite high heel makes it comfortable?**

**\*5. What is most important to you when purchasing a high heel?**

**6. Where do your feet hurt after wearing your high heels for a long period of time?**

☐ Back of heel

☐ Arches

☐ Toes

☐ Side of foot

☐ Top of foot

Other (please specify)

**7. Where else do you hurt after wearing your high heels for a long period of time?**

☐ Calves

☐ Thighs

☐ Knees

☐ Back

Figure 29: Initial User Survey - Picture 2 out of 4

www.surveymonkey.com/s.aspx?PREVIEW\_MODE=DO\_NOT\_USE\_THIS\_LINK\_FOR\_COLLECTION&sm=c92bRaIbSLwBeyer%2bOSKCb8a5efEE4oCctCt93szEPuX3d -- [SURVEY PREVIEW MODE] High Heel Conf. Reader

(1) Facebook SurveyMonkey - Question Builder [SURVEY PREVIEW MODE] High Heel Comfort and Style Survey

**7. Where else do you hurt after wearing your high heels for a long period of time?**

☐ Calves  
☐ Thighs  
☐ Knees  
☐ Back  
☐ Ankles  
☐ Hips

Other (please specify)

**8. How long can you last STANDING in your high heels?**

☐ less than 1 hour  
☐ 1-2 hours  
☐ 2-3 hours  
☐ 3-4 hours  
☐ 4-5 hours  
☐ 5+ hours

Other (please specify)

**9. How long can you WALK/DANCE in your heels?**

☐ Less than 1 hour  
☐ 1-2 hours  
☐ 2-3 hours  
☐ 3-4 hours  
☐ 4-5 hours  
☐ 5+ hours

Other (please specify)

Figure 30: Initial User Survey - Picture 3 out of 4

www.surveymonkey.com/s.aspx?PREVIEW\_MODE=DO\_NOT\_USE\_THIS\_LINK\_FOR\_COLLECTION&sm=c92bRaIbSLwBeyer%2bOSKCb8a5efEE4oCctCt93szEPuX3d -- [SURVEY PREVIEW MODE] High Heel Conf. Reader

(1) Facebook SurveyMonkey - Question Builder [SURVEY PREVIEW MODE] High Heel Comfort and Style Survey

☐ 4-5 hours  
☐ 5+ hours

Other (please specify)

**9. How long can you WALK/DANCE in your heels?**

☐ Less than 1 hour  
☐ 1-2 hours  
☐ 2-3 hours  
☐ 3-4 hours  
☐ 4-5 hours  
☐ 5+ hours

Other (please specify)

**10. Have you every taken off your high heels and walked barefoot because the discomfort was too much?**

☐ Yes  
☐ No

Done

Powered by **SurveyMonkey**  
 Check out our [sample surveys](#) and create your own now!

Figure 31: Initial User Survey - Picture 4 out of 4

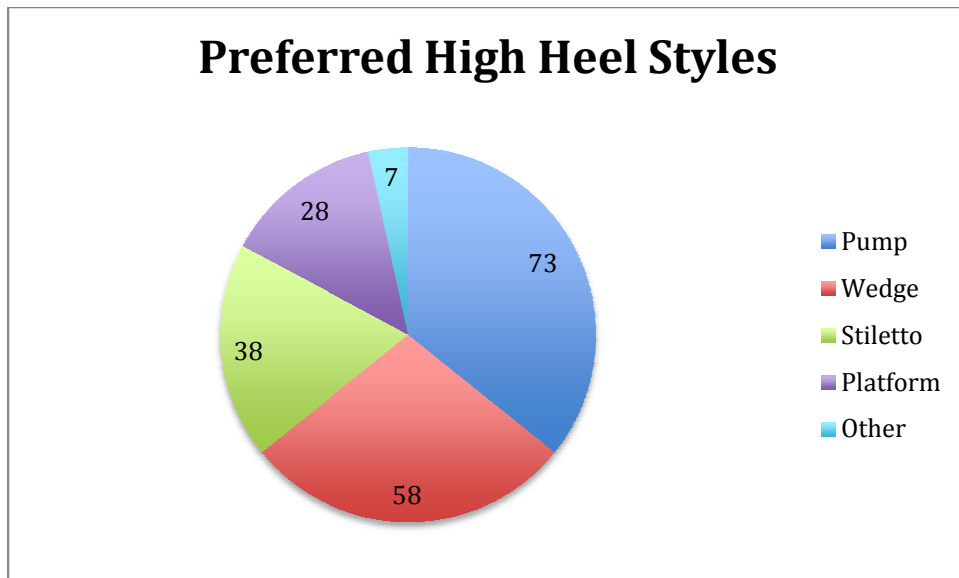


Figure 32: Pie Chart of User Survey Results - Preferred High Heel Styles

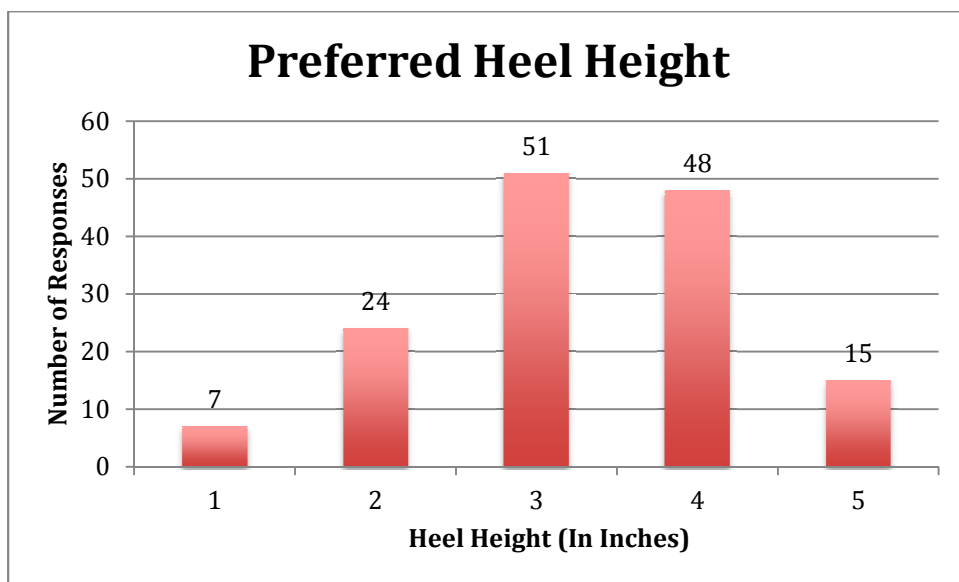


Figure 33: Bar Chart of User Survey Results - Preferred Heel Height

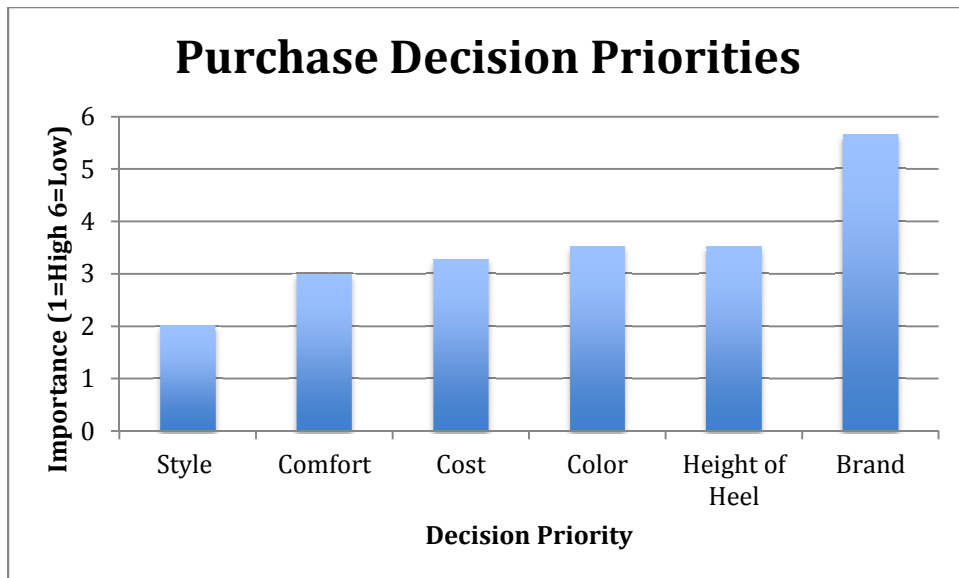


Figure 34: Bar Chart of User Survey Results - Purchase Decision Priorities

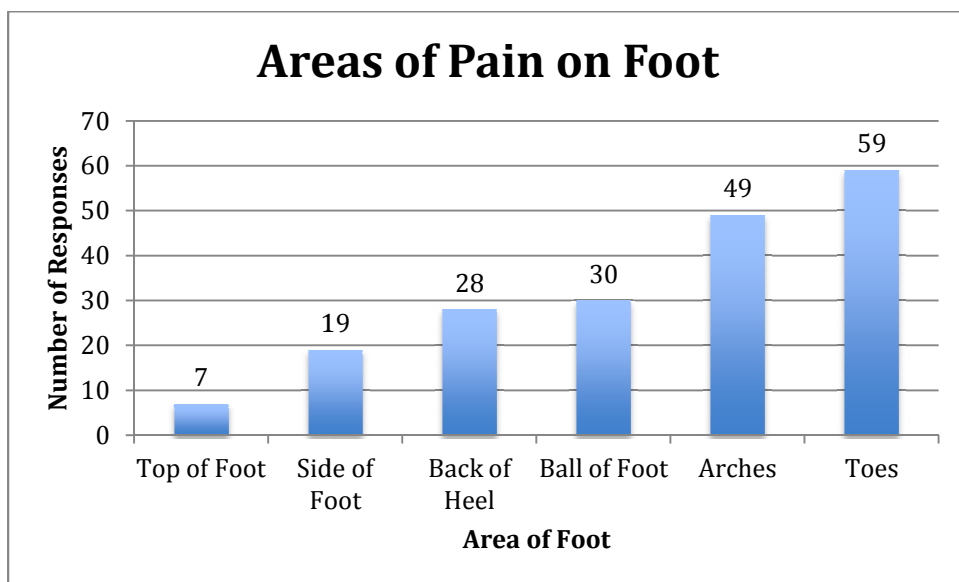


Figure 35: Bar Chart of User Survey Results - Purchase Decision Priorities

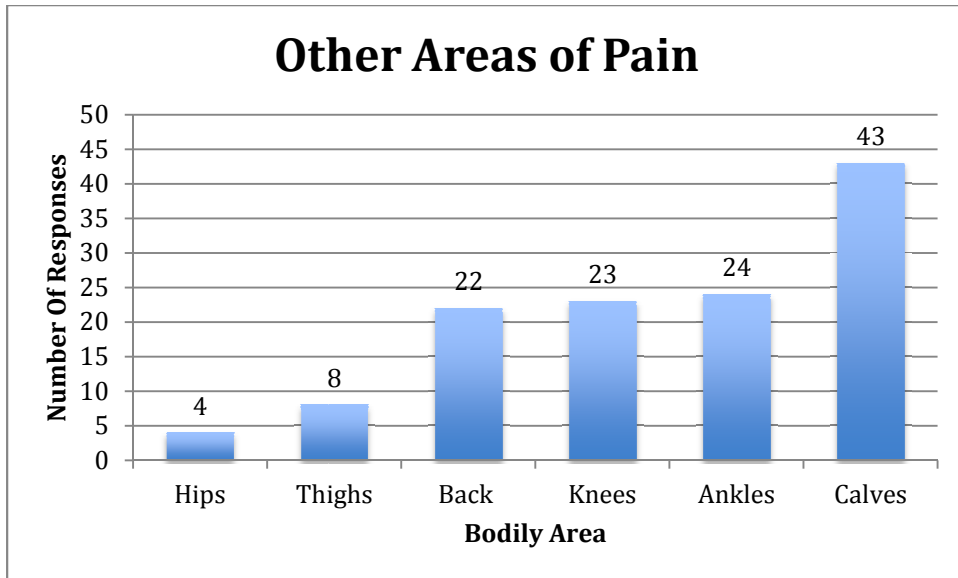


Figure 36: Bar Chart of User Survey Results - Other Areas of Pain

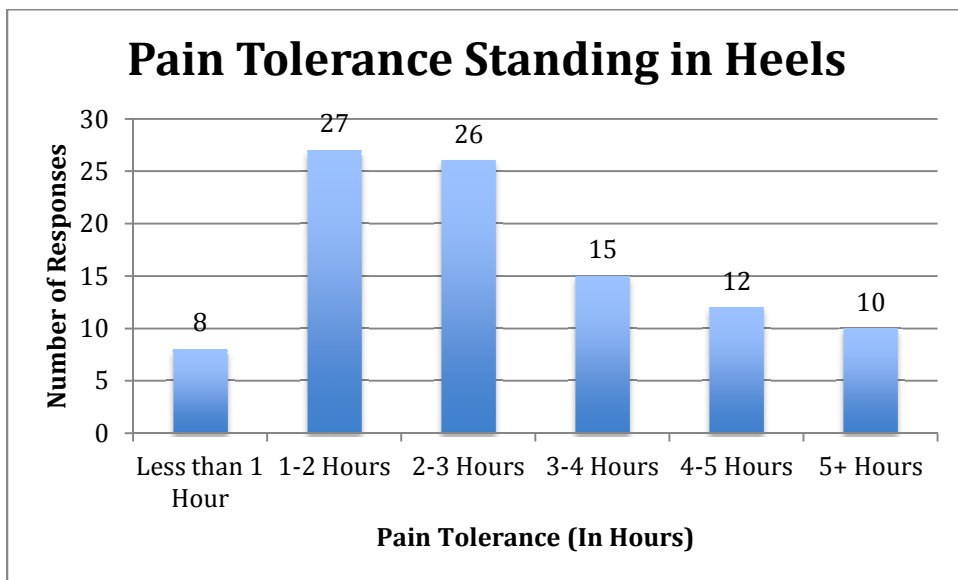


Figure 37: Bar Chart of User Survey Results - Pain Tolerance Standing in Heels



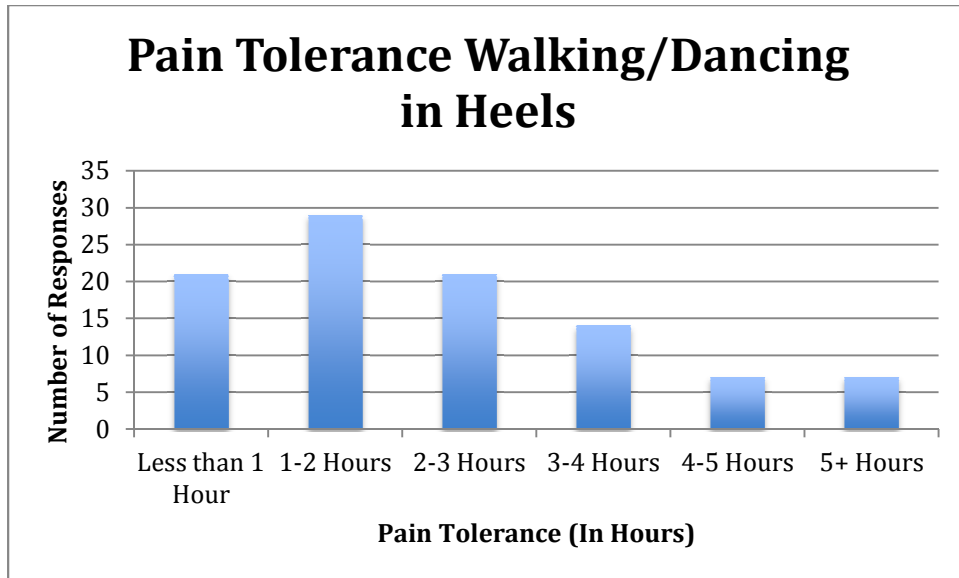


Figure 38: Bar Chart of User Survey Results - Pain Tolerance Walking/Dancing in Heels

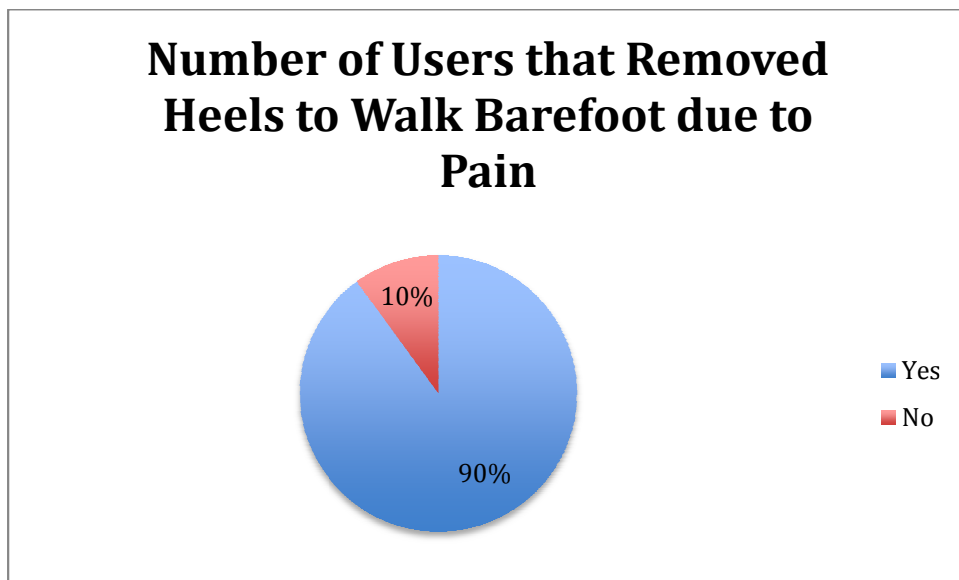


Figure 39: Pie Chart of User Survey Results - Number of Users that Removed Heels to Walk Barefoot due to Pain

Compression	Left Height (inches)	Right Height (inches)	Left Compression Length	Right Compression Length	Left Compression Ratio	Right Compression Ratio	Left Compression Percentage	Right Compression Percentage
No Weight	3.88	3.81	0.00	0.00	0.00	0.00	0.00	0.00
Natural Weight	3.63	3.56	0.25	0.25	0.06	0.07	6.45	6.56
Left Weight	3.44	3.81	0.44	0.00	0.11	0.00	11.29	0.00
Right Weight	3.88	3.38	0.00	0.44	0.00	0.11	0.00	11.48

Table 2: Material Compression Results

$$\text{Compression Ratio} = \frac{(\text{Height1} - \text{Height2})}{\text{Height1}}$$

Equation 10: Material Compression Ratio

$$\text{Compression Percentage} = \text{Compression Ratio} * 100$$

Equation 11: Compression Percentage

Arch Angle	Horizontal Length (inches)	Vertical Height	Angle (degrees)
Stiletto	3.5	4	48.81
Wedge	4.5	2.75	31.4
Prototype	5.25	2.25	23.19

Table 3: Arch Angle Test Results

Surface Area	A(heel)	A(toe)	A(arch)	A(total)
Pump	0.1875	5.6875	0	5.875
Wedge	3.828125	4.8125	4.8125	13.45313
Prototype	7	10.3125	2.40625	19.71875

Table 4: Ground Contact Surface Area Test Results

Labor Costs		Time Study		Observed Time (in mins)	Rating	Normal Time (in mins)	Allowance	Standard Time
Hours working per day	8	Machine/Prepare Soles		60	90	54	0.05	56.7
Wage/hour	12	Build Mold around Soles		60	90	54	0.05	56.7
Number of working days in a week	5	Measuring/Mixing		10	100	10	0.05	10.5
Number of working weeks in a year	52	First Pour		1	100	1	0.05	1.05
Labor Cost per Year per Worker	24960	Build New Mold		45	90	40.5	0.05	42.525
Number of Workers	1	Measuring/Mixing		10	100	10	0.05	10.5
Wage per year	24960	Second Pour		1	100	1	0.05	1.05
Social Security Tax (6.2%)	1547.52	Demold		5	100	5	0.05	5.25
Medicare (1.45%)	361.92	Clean Up		45	90	40.5	0.05	42.525
Federal Unemployment Tax (0.8%)	199.68	Total Time		237		216		226.8
State Unemployment Tax (6.2%)	1547.52	Hours/unit		3.78				
Employment Training Tax (0.1%)	24.96							
Worker's Compensation (8% -- Assembly Worker)	1996.8							
Final Labor Cost per year	30,638.40	Working hours in a month		173.33				
Working hours in a year	2080	Number Of Units in a Month		45.86				
Labor Cost per unit	55.68	Rounded units per month		45				
		Number of Units in a year		550.26				
		Rounded units per year		550				

Figure 40: Spreadsheet of Labor Cost Calculations

$$\text{Normal Time} = \text{Observed Time} * \text{Rating}$$

Equation 12: Labor Normal Time Equation

$$\text{Standard Time} = \text{Normal Time} * \text{Allowance}$$

Equation 13: Labor Standard Time Calculation

$$\begin{aligned} \text{Number of Units (In a month or Year)} \\ = \text{Total Working Hours in That Time Frame} \div \text{Hours per unit} \end{aligned}$$

Equation 14: Number of Units Produced

*Total Labor Cost per Unit*

$$= (\text{Hours per Unit} \div 2080 \text{ Working hours in a year}) \\ * \text{Total Labor Cost per Year}$$

**Equation 15: Labor Cost Per Unit**

*Total working hours in a month*

$$= \frac{\text{Number of working hours in 1 year}}{12 \text{ months}} * \text{Number Of Workers} \\ = \frac{\left(\frac{8 \text{ hours}}{\text{day}}\right) \left(\frac{5 \text{ days}}{\text{week}}\right) \left(\frac{52 \text{ weeks}}{1 \text{ year}}\right)}{12 \text{ months}} * \text{Number Of Workers} \\ = \frac{2080 \text{ hours/year}}{12 \text{ months}} * \text{Number Of Workers} \\ = 173.3 \text{ hours/month} * \text{Number Of Workers}$$

**Equation 16: Total Working Hours per Month**

Item	Number of Units	Price	Cost	Amount used for one unit	Cost/Unit
Bubble Totes for mold	2	5.39	10.78	1	10.78
Shoes	2	15.11	30.22	1	30.22
Mold Materials	1	41.36	41.36	1	41.36
Mold Materials	1	35.47	35.47	0.5	17.73
Hot Glue	20	9.63	9.63	0.2	1.93
Cardboard	480	25.90	25.90	0.0021	0.05
Wax	1	6.99	6.99	0.1	0.70
<b>TOTAL Per Unit</b>					<b>102.77</b>

**Figure 41: Spreadsheet of Material Cost Calculations**

Initial	Item	Price	Ongoing	Item	Price
	Hot Glue Gun	27.00		Rent	750.00
	Mixing Bowl	1.00		Electric Utilities	35.00
	Spatula	1.00		<b>Total Overhead Cost Per Year</b>	<b>9,420.00</b>
	Razorblade Knife	9.21		Number Of Units Produced	550
	Dremmel Kit	97.92		<b>Total Overhead Cost Per Unit (Yearly)</b>	<b>17.13</b>
<b>Total Startup Cost</b>		<b>136.13</b>			
<b>TOTAL FIXED COST</b>	<b>9,556.13</b>				

**Figure 42: Spreadsheet of Overhead and Fixed Costs**

Start-Up Costs	136.13
Unit Variable Cost (Yearly)	158.45
Yearly Overhead Cost	9,420.00
Total Overhead Cost Per Unit	17.13
Volume (Monthly)	45
Volume (Yearly)	550
Yearly Variable Costs	87,145.22
Monthly Variable Costs	7,262.10
Total Yearly Cost (for year 1)	96,701.35
Profit Margin	0.2
Sales Price	190.14
Yearly Revenue	104,574.27
Monthly Revenue	8,714.52
Profit for year 1	7,872.91
Contribution Margin	17%

**Figure 43: Financial Analysis Calculations**

*Variable Cost Per Unit = Labor Cost Per Unit + Material Cost Per Unit*

**Equation 17: Variable Cost Per Unit**

*Yearly Variable Costs = Volume Produced Yearly \* Variable Cost Per Unit*

**Equation 18: Yearly Variable Costs**

*Total Yearly Cost = Yearly Variable Cost + Yearly Overhead + Startup Cost*

**Equation 19: Total Yearly Cost**

*Sales Price = Variable Cost Per Unit \* (1 + Profit Margin)*

**Equation 20: Sales Price**

*Yearly Revenue = Volume Produced Yearly \* Sales Price*

**Equation 21: Yearly Revenue**

*Yearly Profit = Yearly Revenue – Total Yearly Cost*

**Equation 22: Yearly Profit**

$$\text{Contribution Margin} = \left( \frac{\text{Yearly Revenue} - \text{Yearly Variable Cost}}{\text{Yearly Revenue}} \right)$$

Equation 23: Contribution Margin

<b>BREAKEVEN</b>	
Breakeven Revenue Y1	57,336.78
Breakeven Volume	301.56
Breakeven Volume Rounded	301

Figure 44: Breakeven Calculation Results

$$\text{Breakeven Revenue} = \frac{\text{Fixed Costs}}{\text{Contribution Margin}}$$

Equation 24: Breakeven Revenue

$$\text{Breakeven Volume} = \frac{\text{Breakeven Revenue}}{\text{Sales Price Per Unit}}$$

Equation 25: Breakeven Volume

INCOME VS UNITS - BREAKEVEN ANALYSIS	Considering that sales price per unit is	190.14											
Number Of Units	50	100	150	200	250	300	350	400	450	500	550	600	
Revenue	9,506.75	19,013.50	28,520.25	38,027.01	47,533.76	57,040.51	66,547.26	76,054.01	85,560.76	95,067.52	104,574.27	114,081.02	
Fixed Cost	9,556.13	9,556.13	9,556.13	9,556.13	9,556.13	9,556.13	9,556.13	9,556.13	9,556.13	9,556.13	9,556.13	9,556.13	
Variable Cost	7,922.29	15,844.59	23,766.88	31,689.17	39,611.46	47,533.76	55,456.05	63,378.34	71,300.64	79,222.93	87,145.22	95,067.52	
Total Cost	17,478.42	25,400.72	33,323.01	41,245.30	49,167.59	57,089.89	65,012.18	72,934.47	80,856.77	88,779.06	96,701.35	104,623.65	

Table 5: Breakeven Analysis Graph Data

EXTRA OPERATORS ANALYSIS					
Number of Operators	1	2	3	4	5
Volume	550	1100	1650	2201	2751
Unit Variable Cost	158.45	203.81	249.1658583	294.5258583	339.8858583
Total Yearly Variable Costs	87,145.22	224,186.44	411,123.67	648,251.41	935,026.00
Total Startup Cost	136.13	272.26	408.39	544.52	680.65
Total Yearly Overhead	9,420.00	9,420.00	9,420.00	9,420.00	9,420.00
Total Cost	96,701.35	233,878.70	420,952.06	658,215.93	945,126.65
Sales Price	190.14	244.57	299.00	353.43	407.86
Revenue	104,574.27	269,023.73	493,348.40	777,901.70	1,122,031.20
Profit	7,872.91	35,145.03	72,396.34	119,685.76	176,904.55
Contribution Margin	0.17	0.17	0.17	0.17	0.17
Breakeven Revenue	57,336.78	58,153.56	58,970.34	59,787.12	60,603.90
Breakeven Volume (Rounded)	301	237	197	169	148

Table 6: Extra Operator Analysis Results

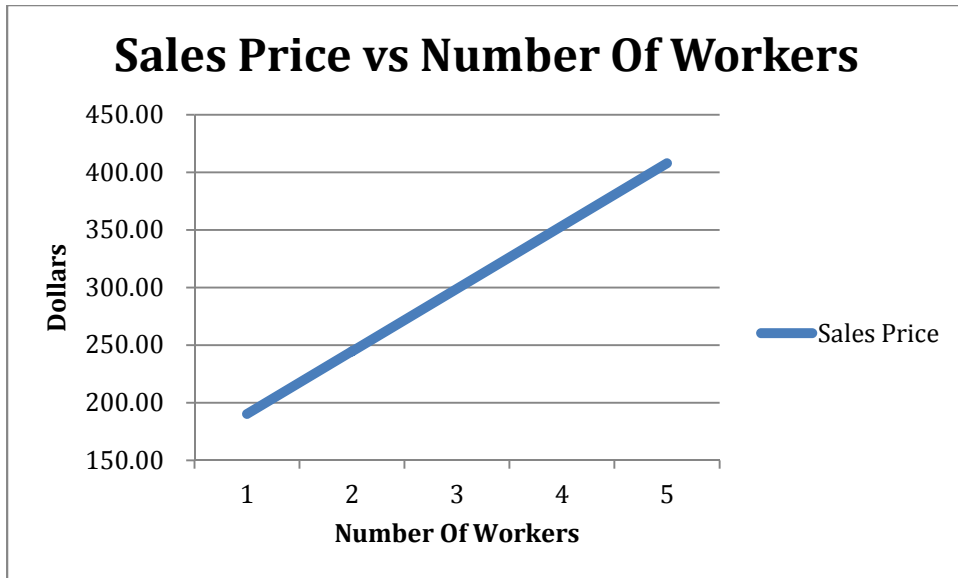


Figure 45: Graph of Sales Price vs. Number Of Workers

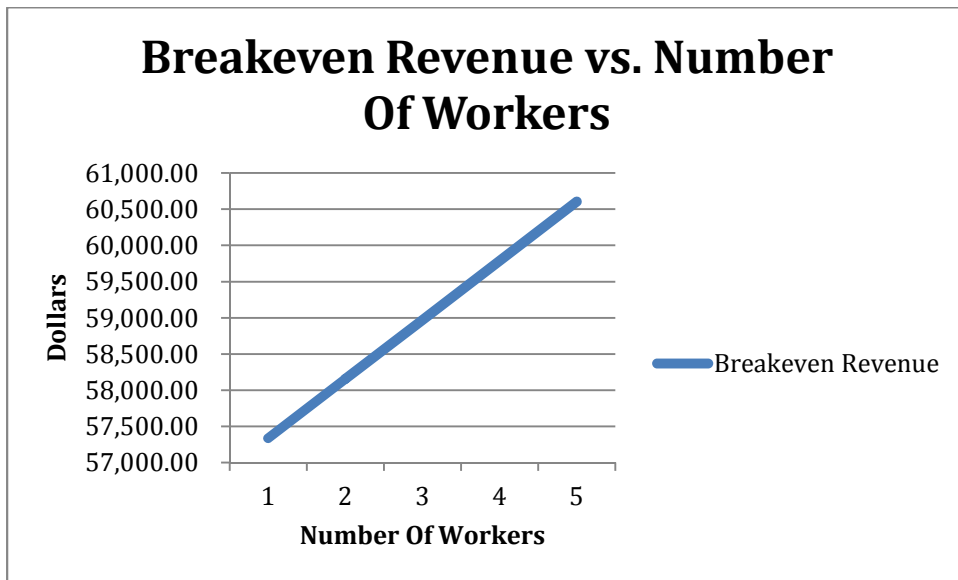
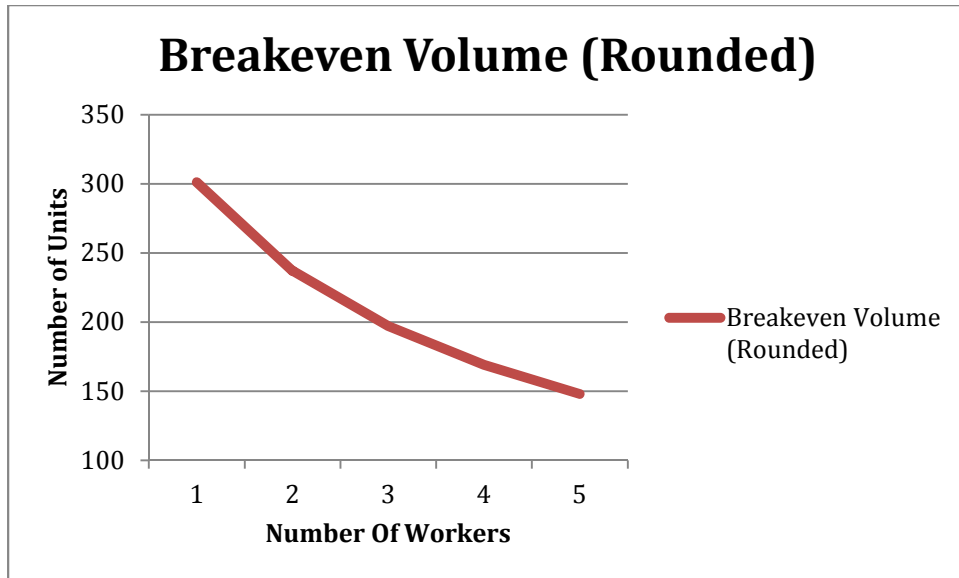


Figure 46: Graph of Breakeven Revenue vs. Number Of Workers



**Figure 47: Graph of Breakeven Volume vs. Number Of Workers**

	Volume	550	Variable Cost Per Unit	158.45						
Total Variable Cost	87,145.22	87,145.22	87,145.22	87,145.22	87,145.22	87,145.22	87,145.22	87,145.22	87,145.22	87,145.22
Total Fixed Cost	9,556.13	9,556.13	9,556.13	9,556.13	9,556.13	9,556.13	9,556.13	9,556.13	9,556.13	9,556.13
Total Cost	96,701.35	96,701.35	96,701.35	96,701.35	96,701.35	96,701.35	96,701.35	96,701.35	96,701.35	96,701.35
Sales Price Margin	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
Sales Price	166.37	174.29	182.21	190.14	198.06	205.98	213.90	221.82	229.75	237.67
Revenue	91,502.48	95,859.74	100,217.01	104,574.27	108,931.53	113,288.79	117,646.05	122,003.31	126,360.57	130,717.83
Profit	(5,198.87)	(841.61)	3,515.65	7,872.91	12,230.18	16,587.44	20,944.70	25,301.96	29,659.22	34,016.48
Contribution Margin	0.05	0.09	0.13	0.17	0.20	0.23	0.26	0.29	0.31	0.33
Breakeven Revenue	200,678.73	105,117.43	73,263.66	57,336.78	47,780.65	41,409.90	36,859.36	33,446.46	30,791.97	28,668.39
Breakeven Volume	1,206.23	603.12	402.08	301.56	241.25	201.04	172.32	150.78	134.03	120.62

**Table 7: Results of Sales Price Margin Sensitivity Analysis**

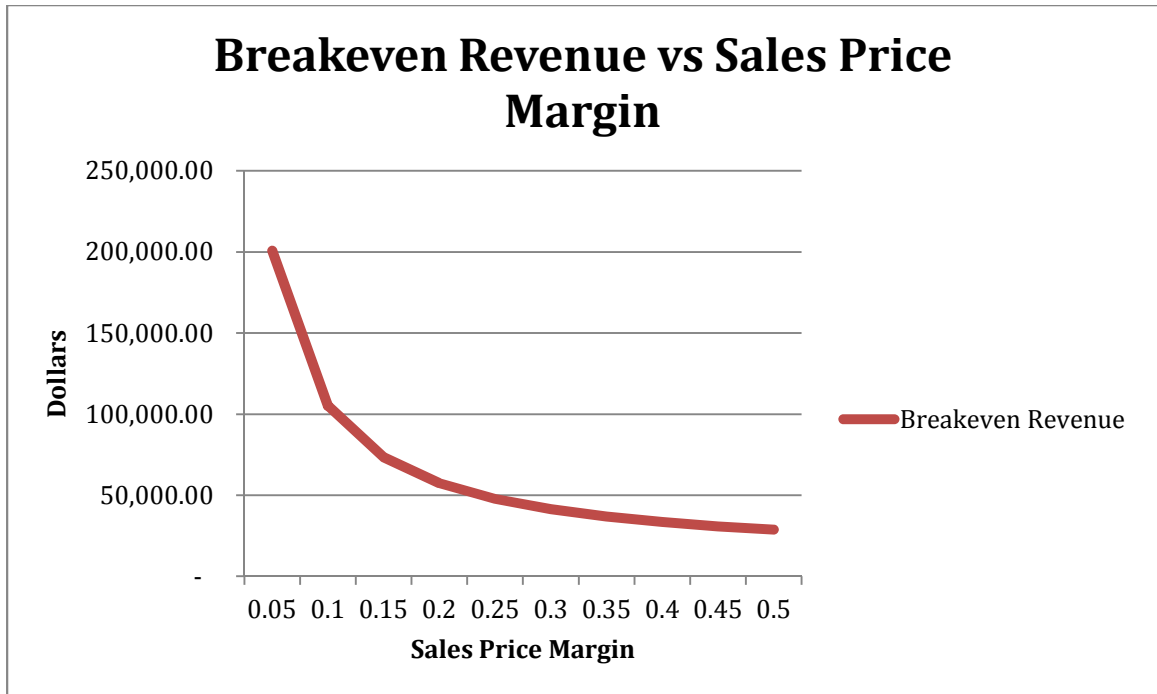


Figure 48: Breakeven Revenue vs. Sales Price Margin

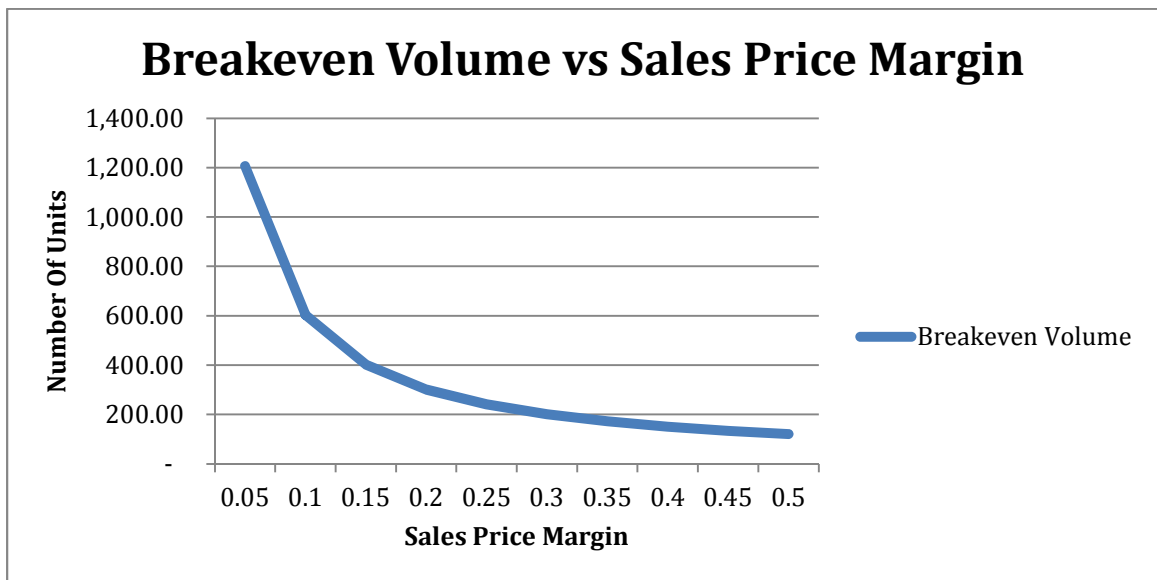


Figure 49: Breakeven Volume vs. Sales Price Margin